Leveling the Playing Field Thorough Incorporating 3D Printing in Capstone Courses

Gregory F. Hickman
and
Michael A. Latcha Ph.D.

Dept. of Mechanical Engineering
Oakland University
Rochester, MI 48309
Email: gfhickma@oakland.edu

ABSTRACT

One of the last courses undergraduate engineering students typically take is a senior capstone design course. At Oakland University, this experience combines seniors from the mechanical, electrical and computer engineering programs into multidisciplinary groups which tackle a proscribed problem statement. This single semester experience typically culminates in a competition between the design groups. After moving into a new building in Fall 2014, Oakland University now has a state-of-the-art design space with associated technology dedicated for this effort. In addition to a traditional machine shop with a full range of manual and CNC tools, 3D FDM machines (uPrint and Fortus) were added to the resources available for students' use. Incorporation of rapid manufacturing technology into the available resources offers distinct advantages to the students, and has greatly increased the quality, reliability and complexity of finished products. In this paper we will compare and contrast the last two semesters' projects, with emphasis placed on how utilizing rapid prototyping has contributed to improved student outcomes.

INTRODUCTION

Capstone or Senior Design courses are an important opportunity for students to solve a real world problem before graduation. At Oakland University we utilize a "Melting Pot" model which combines students from Electrical and Computer Engineering and Mechanical Engineering departments in the capstone course into multidisciplinary senior design teams . The advantages of this approach have been previously described in both regional and national publications.[1-3] During the Fall of 2014 the School of Engineering and Computer Science (SECS) at Oakland University was relocated to a new facility which houses the new Senior Design Lab (SDL). This lab consists of a 3000 sq-ft dedicated design space, with capacity for up to 100 students working in up to 14 design groups, each with a full suite of software and hardware tools. This is in contrast to previous years where students would have had to find the appropriate equipment, software and space in general in which to design and build their solution to the engineering problem.

BACKGROUND - SENIOR DESIGN STUDENTS

In the capstone course students from different disciplines, with different skill sets, come together and engineer a solution to a defined problem. It is from this diversity that unique solutions that go well beyond the vision of the instructor are possible, while at the same time some skills necessary for successful completion of a project may be present. Manufacturing knowledge and experience with machine tools vary widely amongst this student population and can lead to challenges for some teams to accomplish their goals. To help alleviate this discrepancy, the SDL space was equipped with two Fused Deposition Modelers (FDM), also known as 3-D printers. Through the use of 3-D printers, the need for understanding of machining methods, equipment and procedures is largely eliminated from the build equation. Students get a relative "what you see is what you get" component, in a relatively short time frame. While this technology allows the user to build parts that may not be production ready, they are built to the size and geometry supplied such that what goes together virtually will go together physically.

BACKGROUND - RAPID MECHANCICAL PROTOTYPING

Rapid mechanical prototyping can take on many forms and falls within many categories. For the purpose of this paper we will only concern ourselves with additive manufacturing technologies that can be broken into four distinct groups based upon the process by which they manufacture the parts. Furthermore these technologies are based of the solid freeform fabrication process (SFF).[4] The attributes of SFF technologies:

- building of complex 3D geometries
- automatic CAD based process planning
- use of a generic part build machine without part specific tooling
- minimal to no human interaction to build

Inside this framework there exist four broad categories of SFF additive processes.[4]

- Laser Photolithography - acrylic or epoxy photo cured polymer
- Laser Fusion - selective laser sintering (SLS)
- Lamination - laminated object manufacturing (LOM)
- Extrusion - fused deposition modeling (FDM)

Each process utilizes a different approach to building parts and support material (fixturing) during the build process, but effectively can all build the same parts. For brevity the focus of this discussion will be on the extrusion type of SFF.

Stratasys Inc. was the first commercially available extrusion type modeler. The process involves ABS wire being extruded through a nozzle along the build path for the part. The user translates a CAD file into the stl format and processes it through the machine's path generation software. This processed file with both the path of the part and any support are the machine instructions for the build process, which deposits layer after layer of both part and support materials. After the build is complete the support material is removed from the part with a secondary process, either mechanically, chemically or both.

BACKGROUND - OAKLAND UNIVERSITY

Students at Oakland University have access to both a traditional machine shop, with a normal complement of subtractive manufacturing methods, in addition to three FDM additive manufacturing devices. Three printers are available for senior design, a uPrint SE Plus, a Fortus 360mc and a Dimension 1200e printer, all being capable of printing in ABS, with the Fortus additionally capable of printing in Nylon 12 (among other materials). In order for parts to be manufactured with an additive technique, students must fully realize a design virtually prior to manufacture in a computer aided design (CAD) package. By encouraging students to consider this option we drive students to a virtual prototyping of their concept rather than an iterative build methodology.

In the past it was apparent that students would rough out their concept, build a prototype and work through the development stages without a full realization of their final design. This is akin to a maker mentality or build/test/build workflow. It is the intention of capstone courses to give students a real world experience prior to graduation. To that end a virtual design / analysis structure is more akin to real world design problems, and therefore as a byproduct of utilizing rapid-prototyping technology we drive students to this methodology.

SKITTLE® SORTING - WINTER 2014

In the winter semester of 2014 students at Oakland University were assigned to develop a Skittle® sorting machine. During the 15 week semester students were required to design an apparatus capable of sorting 1800 Skittles®, according to color into 8 distinct bins, one for each color, in under 5 minutes. The apparatus was to be self-standing, minimal in overall dimension, time the process of sorting and keep an accurate count for each color bin. Students were divided between 6 groups, each with computer, electrical and mechanical engineering majors, with a diverse mix of manufacturing background and experience. It is worth noting that this was the last semester before the opening of the SDL.

All of the solutions were gravity based that started with funneling Skittles® into a tube, whereupon the color of the skittle could be read. The main approach of the six teams was to use multiple gates leading to the correct bins. One of these groups achieved this with never stopping the Skittle's® decent. The main difficulties faced by this team were how to accurately read the color rapidly and how to make the gates precise enough so they could actuate at the appropriate time.

The remaining five teams took a binary approach to sorting the skittles. While also using a gravity-type machine, these teams elected to make a series of binary color decisions, first sorting by dark and light, then subsequently refining the color detection as binary decisions. The thought process behind this decision was to simplify the construction of their machine, but with gravity powered devices this quickly became unwieldy due to the height required for a physical decision tree.

Due to the uncertainty of the kinematics, most groups chose to construct their Skittle® sorting devices out of wood for maximum flexibility, and easy availability of materials and tools.

Unfortunately, the materials chosen and the techniques generally used were not up to extended testing and revision.

FASTENER COUNTING - FALL 2014

For the Fall 2014 semester students were assigned to develop an apparatus capable of performing a count from 1 to 6 fastener components of six different types. The apparatus could be modified between rounds (that is, to another fastener type), but this had to be accomplished in a short period of time with minimal work. This concept was presented to the students as a solution to assembly line waste both in material and time. Students were divided into 8 groups with a mix of majors and manufacturing backgrounds. At this time the SDL was fully operational.

The students' approach to solving this problem fell into one of three general types, gravity fed, tumbler type, and vibrational type. Each of these solutions contained at least one component that was 3-D printed, if not more. Each team had the ability to freely decide what methods of manufacture they would utilize and how and where it would be produced. The quantity of components in the assembly that were built with rapid prototyping (RP) technologies was not a factor in the successful completion of the designs, but allowed the more dimensionally critical elements to be precise enough to complete the task at hand.

The gravity fed type solutions involved funneling a quantity of the part to be counted onto a rotating disk. This disk contained features that would allow one component to enter the disk at a time, with multiples of these features around the circumference of the disk. In order to guarantee that a part was present an IR sensor was mounted in the count bucket to ascertain each successful drop event, and the disk would continue to spin until the correct quantity was achieved. Three of the eight teams took this approach to solve the problem. One team relied primarily on RP built components, while the other team constructed the majority of the structure and funnel parts out of other manufacturing methods.

The tumbler type solutions involved a large drum in which the parts were dumped, would rotate and fill in features around the circumference of the floor of the disk. Upon successful rotation to the drop point, the component would be dropped into a collection bin. Much like the gravity fed solutions, part counting at the interface between the drum and the collection bin was necessary in order to validate the quantity delivered. Four of eight teams took this approach to the problem, with almost identical use of RP technologies. Teams primarily printed the drum and collection features for their concepts. Some of the teams additionally printed the collection bin as well as the door to this bin. The majority of the structure for these concepts was built with other manufacturing techniques such as wood and preformed metal tubing.

The final type was vibrational and was attempted by one team. The primary feature for this type is a ramped vibration bowl, common in assembly environments. This feature was procured from an existing bowl manufacturer to eliminate the time needed to create a large component and keep costs down for the final product. At the top of the bowl the team had to mount specific channels to take the components and deliver them to the counting box. Six unique channels needed to be built to accommodate the six parts tasked for this exercise. Each of the channels were built using RP technology which allowed the team to integrate into the channel features to mount two solenoids as gates along the channel to keep an accurate count of the components.

SKITTLE® COUNTING – FALL 2015

In the fall of 2015 many different projects were offered to the students to work on. One team of students had determined that they would address the Skittle® sorting problem previously assigned to students in this course. This one team would follow exactly the same rules as the previous semester and build an apparatus to count and sort Skittles by color. While not a direct competition as in past years, their performance would be compared to the results from the previous semester.

As with the part counting exercise, these students had access to the SDL RP technologies to build their solution. The team ended up with a novel concept as compared to the previous semester, which involved having a funnel device deliver the candies to a rotating chain. The links of the chain were designed such that one Skittle® could perch on the top surface and would rotate along the chain's path. Upon successful travel along the chain path, each Skittle® would be presented to a color sensor and the color determined. Further along the path, a puff of air would remove the Skittle® from the chain and go into its collections bin. When the color of the Skittle® was ascertained, a counter of the correct type was incremented. The chain would continue along its path until it was located under the funnel again. In order to improve the throughput of this apparatus, two identical systems were utilized so that any one link would move two Skittles on its completion of the chain path.

COMPARING THE SEMESTERS

While these three semesters did not involve exactly the same project, they are very similar in their design project goals, which involved determining how many of an object is placed in the queue to be delivered to the customer. In order to be successful in achieving that goal, teams must design, simulate and build an apparatus that works every time and on time. In order to achieve these goals it is important that the dimensional accuracy and precision of the design be met in order to eliminate binding issues, missing results from interfacing electronics (counters) and that the design be robust enough to work through the trials and the competition phases of the projects.

Students from the winter 2014 semester were at somewhat of a disadvantage compared to those from later semesters, as Oakland University did not have the RP technologies the later students were granted access to. The construction methods of these students resulted in large variation of dimension, less accurate mounting of electronic components and less robust machines. The primary construction method was wood, which on its own is not a bad building material, as long as precision machining is utilized to achieve the components of the machine. Additionally, it is worth noting that the lack of centralized computing resources for this class resulted in significantly less analysis being performed on a solution (virtual prototyping) and hence build issues were not discovered earlier in the design stage.

Most of the flaws see in the winter 2014 semester were eliminated in the fall of 2014, with the opening of the SDL and the ready availability of RP technologies. Teams in these following semesters were able to build precise, dimensionally accurate components with this technology, which allowed students to focus less on manufacturing constraints and more on design related constraints. It is this leveling of the component manufacturing field that allowed for more robust designs at the end of the semester. Another factor that helped improve the designs in these semesters is the push to do more “engineering” through system simulations, rather than “tinkering” from the build / test / modify cycle used in the past. The SDL was again a major contributor to this, as students had a centralized and dedicated location to perform all analysis for their designs.

A direct comparison of the solutions is possible with the Fall 2015 design for a Skittle® sorter. This team’s approach of a chain drive mechanism allowed for accurately delivering one Skittle® at a time to a color sensor. In doing so it was critical that the chain elements be dimensionally accurate and by 3D printing allowed for the custom carrying feature on an otherwise traditional link element. By building these custom links using additive manufacturing, the team eliminated a manufacturing stumbling block that other teams had seen in the previous attempts.

CONCLUSION

Rapid Prototyping (RP) technologies are not new in the marketplace as they have been in use since the early 1980’s. The relative cost of using these technologies on the other hand has been dramatically reduced to the point that utilizing this technology as a part of coursework is readily feasible. It is estimated that the total cost to produce one cubic inch of material in Oakland’s RP machines is $8.00. With this low cost, senior design students can now avail themselves of this technology in order to build dimensionally accurate complex components. While it is not a panacea approach, integrating and utilizing such technology where appropriate, in conjunction with virtual simulation tools, can assist students in achieving more robust solutions to their design projects. With the relative ease with which this technology works, it could be even taken out of a semester or two semester program and implanted in much shorter design / project based curricula. The overall effect of having access to these technologies in the classroom, is to reduce the need for precise manufacturing knowledge for each and every member of the team. While traditional subtractive techniques are valuable and critical skills that some must know, not all students on a multidisciplinary team with different majors are suited for this side of the curriculum. Therefore RP is a greater leveler of this manufacturing playing field, when our goal is to examine the overall ability to engineer a solution to a problem and not the ability to manufacture a particular solution.

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